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NUMERICAL AND EXPERIMENTAL THERMAL ANALYSIS OF AL6061 ALLOY FRICTION STIR WELDING

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ABSTRACT

The aim of this research work is to thermally analyze Al6061 alloy friction stir welding (FSW) using numerical and experimental methods. The Infrared (IR) thermometer was used to measure the temperature profile during FSW at various locations of the specimen in the FSW direction. Three-dimensional finite element models were used to investigate the thermal profile in the welding of Al alloy and the heat sources generated due to the friction reaction between the tool shoulder and welded materials. The analysis helps to understand the dynamics of the FSW, the thermal profile along the longitudinal, lateral and through the thickness of welded materials. The experimental results showed that the maximum temperature is directly proportional to the tool rotation speed but inversely proportional to feed rate of the FSW.

KEYWORDS**:** ***Friction Stir Welding & Al-6061 Thermal Analysis***

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Original Article

1. INTRODUCTION

Friction stir welding (FSW) finds numerous potential applications in aerospace, automotive, domestic and marine industries due to the high efficient joining of two similar and dissimilar materials. FSW consumes 42% lesser energy than gas metal arc welding (GMAW) and utilizes approximately 10% lesser material for the design criteria of similar maximum tensile force without liberation greenhouse gases [1]. When the FSW tool is traversed along the line of welding, the tool shoulder and pin stir the material in their surroundings. For the formation of a weld, a minimum amount of energy input per unit length traveled is required [2-4]. Tool materials are desired to be significantly harder and stronger than the base metal, to ensure effective material flow. Friction between the tool surface and base and the plastic flow result in the generation of heat. This leads to the softening of the welding material [5]. As a result of thermal energy produced by the friction between the tool and the work piece due to stirring action of FSW tool aid in forming the weld [6-8]. An FE three dimensional models were developed for analysis of the thermal profile of butt welding of Al alloy. The temperature profile (heat transfer profile) influenced on wear resistance and joint strength of the weld materials was studied. Hsu and Hwang [9] used a commercial finite element code—DEFORM 3D—to conduct a simulation of the plastic deformation of magnesium AZ31 alloy sheets during FSP. The analytical results of temperature, strain, and stress distributions inside the work-piece and the head tool can provide useful knowledge for tool pin design in FSP. However, process control of the tool in pin plunging, preheating, and traversing while obtaining a successful weld has not been discussed thoroughly in the previous literature available. The objective of this work is to study the thermal behavior of the

FSW process through simulation and experimental and to achieve a better joint efficiency by optimizing the parameters.

Table 1: Chemical composition of Al 6061 Alloy

Si	Cu	Mg	Cr	Mn	Ti	Al
0.6	0.2	1.0	0.15	0.1	0.1	Remainder

2. EXPERIMENTAL STUDY

240 x 50 x 6 mm dimensioned Al 6061 alloy plates were used for investigating thermal analysis of FWS butt welding process due to complexity in conventional welding. The chemical compositions of aluminum given are in Table 1. The FWS experiments were carried out for three tool speeds (575, 800 and 1100 rpm) and four feed rates (10, 15, 20 and 25 mm/min) using a milling machine. The work-pieces were cleaned with acetone to remove all dirt and the oxide layer was removed using milling machine before FWS.

Figure 1: Mastech MS 6530A Infrared Thermometer Measuring Temperature during FSW Process

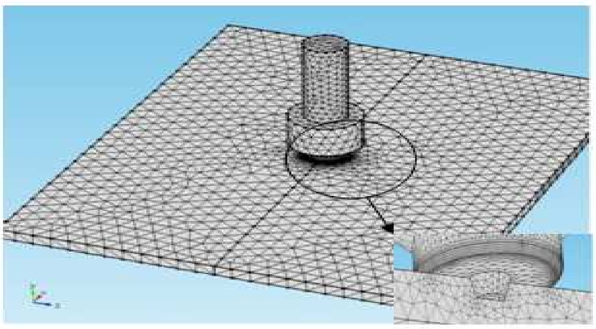

Figure 2: FE Mesh of the Whole Setup for FSW Process

The FSW tools were fabricated using H13 tool steel by grinding with tool head which was maintained at 0ºC. The process is started by positioning the tool close to the surface of the base material. Then, the machine is started and the tool is plunged into the base material to make a drill. Once the pin is completely immersed into the base material, the auto feed is switched ON. The tool rotates and moves to form the weld. Since the heat generated at the contact were seen to be too high, the temperature at the tool shoulder edge and work-piece was measured by M S 6530A, A non-contact infrared thermometer was used to measure the temperature at the shoulder and base material interface (shown in Figure 1). Temperatures were measured and recorded every 0.1 s by a data acquisition system.

3. NUMERICAL INVESTIGATION

The FSW tool and work-piece were modeled such that shoulder touches the top surface of the work-piece and pin made to rotate inside the work-piece to cause the base material to deform and move around the tool, along with the shoulder. Both the top and bottom faces of the workpiece are exposed to the environment with heat transfer coefficient of 25 W/m^{2}K. A 3D tetrahedral element has been used to mesh the entire geometry as shown in Figure 2. The tool region and surrounding area have been meshed very finely. The welded plate has meshed with a total 48219 the tetrahedral for predicting temperature profile in the welded work-piece. The shoulder and pin represent a moving part's as the heat generation of the nodes in each computational time step. Aluminum 6061 and tool steel have been chosen as the base materials and tool material properties respectively and given in Table 2.

Table 2: Base Material Properties for Thermo-Mechanical Analysis [10]

Properties	Sym	Al6061 alloy	Tool Steel
Heat capacity at constant temperature	C_p	900 J/kg-K	460 J/kg-K
Thermal conductivity	k	238 W/m-K	24.3 W/m-K
Coefficient of thermal expansion	α	23×10^{-6} K^{-1}	12 x $10^{-6}K^{-1}$
Density	ρ	2700 kg m^{-3}	7833 kg m^{-3}
Young's modulus	E	70×10^9 N m^{-2}	210×10^9 N m^{-2}
Poisson's ratio	ν	0.33	0.29

In the thermo-mechanical analysis, the effect of variation of feed rate and the rotational speed on the temperature were studied. Feed rate was varied from 10mm/min to 25 mm/min. The rotational speed was varied from 500rpm to 1100rpm.

4. RESULTS AND DISCUSSIONS

FE Results

The initial symmetric model simulations were carried out using COMSOL Multiphysics 5.0. The results show that the temperature is highest where the FSW tool is in contact with the material being welded i.e., aluminum as seen in Figure 3. It can be observed from the Figure 3 that at the wake side, the tool pushes the hot material away, where it comes into contact with fresh material at room temperature ahead of it. The heat transfer process during FSW can be clearly seen in Figure 3 and Figure 4. it can be found that the computed temperature contour at meeting point is very high. Figure 4 shows a clear profile of temperature distribution at the melting point as well as at the tool pin.

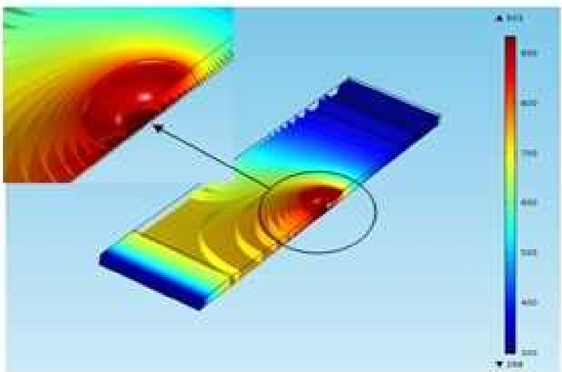

Figure 3: Temperature Distribution in FSW Symmetric Model

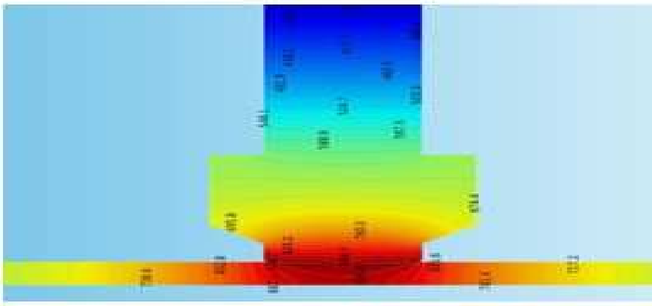

Figure 4: Isotherm at the Tool Center in FSW Process

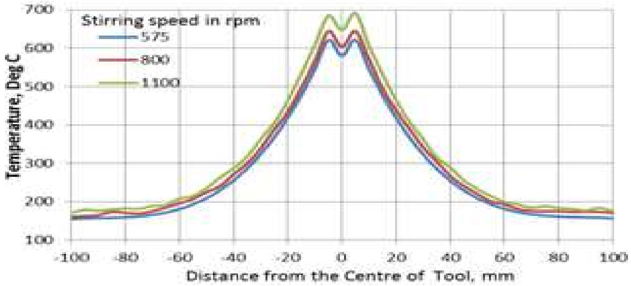

Figure 5: Temperature V/S Width of the Plate at Various Distances from the Tool Center in FSW Process At Feed Rate of 10 Mm/Min

It can be observed from the Figure 4 and Figure 5 that the temperature on the advancing side of the weld joint is slightly higher than that on the retreating side. The difference is about 5°C i.e., the temperature on the advanced side is 5°C more than that on the retreating side. The temperature in the thermo mechanically affected zone is on the higher end (about 700 °C) than expected. This temperature plays a major role in the grain formation in the weld mate. Hence, it plays a major factor in determining the joint efficiency. It is observed that from the maximum temperature attained during the process increases as the rotational speed is increased. From the equation for heat generation, heat generated is directly proportional to the speed of rotation. It cannot be assumed that as the rotational speed is increased infinitely, the temperature will not monotonously increase. As we move to very high rotational speed, the friction between the shoulder and the work piece varies, and thus the temperature too. In the case of variation of feed rate, the temperature decreases with increase in the feed rate. As the feed is increased, the time that the tool spends at a point is reduced. Thus, the heat produced in less. Both these parameters have to be balanced to get the most optimum temperature in the weld zone.

Temperature Measurement and Tensile Test

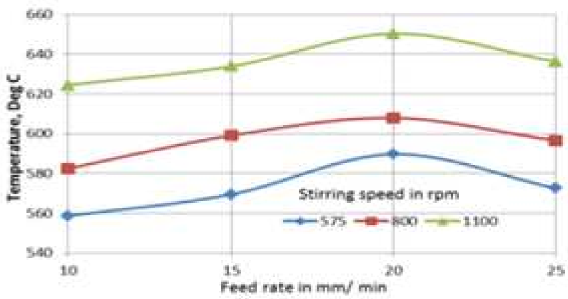

Figure 6: Maximum Temperature Generated FSW Process at Meeting Point as Fraction of Speed and Feed Rate

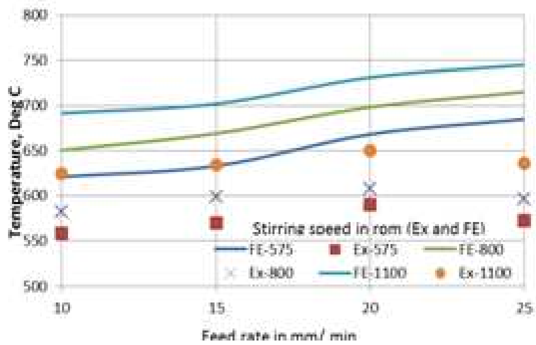

Figure 7: **Comparing the Experimental and Stimulation Temperature in Fraction Stir Welding**

The experimental results of temperature profile as shown in Figure. 6 as a function of distance from the center of the tool, it can be carried-out the thermal analysis using both experimental and FEA analysis. The distribution of temperature profile obtained from experimental analysis along the transverse direction of the work-piece during the FSW for different speeds and different feed rates. The highest temperature was observed within the tool shoulder during FSW and this value varies from 600 to 700 °C irrespective of various speed and feed rates of FSW process. The melting temperature of Al is around 650 °C and of tool material 1450 °C which it confirms the no ferrous material mixed with Al during solid-state joining process. The aim of this research work was to study research aspects of welding process to improve the quality of weld the material based on temperature distribution and to protect the FSW tool from higher temperature and friction. Both base and tool materials strongly depend on the working temperature and also temperature depends on the working parameters such as spindle speed and feed rate.

Figure 7 shows the maximum temperature generated during FSW process at meting point s function of feed rate and speed of the tool. The temperature increases with increasing feed rate until 20 mm/min then it decreases due to heat energy is taken away from he squeezed out material from the work-piece. The temperature continuously is increasing with increasing stirring speed due to less time for exposure and more heat generation at the meeting point. Experimental data is comparing with data obtained from FEA analysis as shown in Figure. 7 and it match with FE data with around 100 °C variations. Both FEA and experimental data indicates that the difference in temperature because of heat transfer has taken place in the form of radiation in the experimental study, which was not considered in FE analysis. The temperature trend almost same as FE results.

5. CONCLUSIONS

Based on the analysis and experimental work carried out in this work, the following conclusion is drawn. Both experimental and numerical results possible to predict a significant effect of FSW parameters on temperature profile on the work-piece. The maximum temperature was found at tool shoulder too irrespective of the speed and feed rate. The maximum temperature variation at the tool shoulder between the speed of 575 and 1100 rpm is less than 50 °C for feed rate (10-25 mm/min) is less than 60 °C. The maximum temperature obtained from the simulation between 650 and 750 °C, which is higher than that of experimental work. The numerically computed temperature results are more consistent with experimental data.

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